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(54) SURFACE ACOUSTIC WAVE AMPLIFIER

(71) We, STANDARD TELEPHONES AND CABLES LIMITED, a British Company, of 190 Strand, London, W.C.2., England, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 This invention relates to a surface acoustic wave amplifier.

Surface acoustic wave (SAW) components tend for a variety of reasons to have high attenuation. This is despite the fact that SAW media are characterised by very low intrinsic transmission losses. Amplification in one form or another is therefore a practical necessity. Electronic amplifiers external to the acoustic substrate have been used very widely in this role, but there are a number of advantages in using an acoustic amplifier. For it is then possible to avoid repeated conversions to an electrical signal for amplification, which would introduce transduction losses of at least 6 dB, constrict bandwidth, and cause spurious signals. Special configurations to avoid these problems do not appear to be readily realisable as planar structures. A SAW amplifier incorporated with the substrate would lead to devices having better performances in these respects, and when constructed in distributed form would provide uni-directional amplification, discriminating against spurious triple transits by reducing them to a relatively low level. Some distributed amplifiers have a bias-dependent phase characteristic which provides a potentially useful electronically variable parameter in SAW systems.

40 The most obvious application of surface wave amplifiers is perhaps to long delay lines, where repeated amplification is necessary to provide a good noise factor. Signal degradation can otherwise become so serious that the system dynamic range is

impaired by the noise threshold of the delay line. The justification for the SAW amplifier is not, however, associated solely with its application in long delay lines. A situation encountered quite commonly in biphase coded matched filters arises when a large number of tightly coupled taps are distributed along an extended delay line path. Equal signals are needed at each tap, and with long configurations direct amplification of the acoustic wave is desirable. As a third area of application, high power is also necessary in the convolver device for efficient action, and convolvers are limited at present by the maximum power handling capacity of the input transducers.

According to the present invention there is provided a surface acoustic wave amplifier comprising a body of piezoelectric material having on a flat surface thereof a pair of separate input and output electro-acoustic transducers arranged so that a surface acoustic wave launched from the input transducer will be received by the output transducer, a plate of monocrystalline magnetic material capable of propagating spin waves excited therein located parallel to and spaced apart from the flat surface of the piezoelectric material between the transducers thereon, the magnetic material having on a flat face thereof means for coupling a pump frequency current to the magnetic material so that spin waves induced in the magnetic material by magneto-elastic coupling with surface waves in the piezoelectric material are amplified and propagated in the same direction as the surface acoustic waves in the piezoelectric material, and means for applying to the magnetic material a polarising magnetic field aligned with the direction of propagation of the surface acoustic and spin waves.

In order that the invention may be readily understood an embodiment thereof will now be described with reference to the

accompanying drawing which depicts in schematic form the elements of a SAW amplifier.

- Amplification may occur when a surface acoustic wave on a suitable substrate is magnetically coupled to a spin wave propagating in a platelet of gallium-doped YIG held close to the substrate surface. In the arrangement shown in the drawing a piezoelectric substrate 1 has a pair of interdigital electroacoustic transducers 2, 3 on its upper flat surface. A typical material for the substrate 1 is lithium niobate. The transducers are of the type described in "Rayleigh and Lamb Waves — Physical Theory and Applications" by I. A. Viktorov, published by Plenum Press, New York, 1967, at pages 8 and 9. Two sets of interdigital contact strips are connected to separate terminals (not shown). When an electrical radio frequency signal is applied to the transducer acoustic waves are launched in opposite directions, normal to the axes of the contact strips, in the surface region of the piezo-electric material. Surface acoustic waves launched by the input transducer 2 are thus propagated towards output transducer 3. The substrate 1 may also be provided with acoustic wave energy absorbing elements (not shown), e.g. wax bodies, placed at the extremities of the substrate to eliminate superfluous surface acoustic waves propagated from the transducers. A plate of monocrystalline magnetic material 4, e.g. gallium doped Yttrium-Iron-Garnet (YIG) is supported above the piezoelectric substrate 1, spaced therefrom by a small air gap 5. The plate 4 is provided with thin metallic film spiral inductors 6 which are connected in parallel to a source of pump frequency current (not shown). A longitudinal polarising magnetic field of about 50G is induced in the structure by means of a permanent magnet 7.
- When a surface acoustic wave launched in the piezoelectric substrate 1 passes beneath the plate 4 in the presence of a magnetic field, a progressive wave motion is excited in the monocrystalline magnetic material. This progressive wave motion results in what are known as magnetoelastic waves. These result from coherent coupling between phonons and spin wave modes. The spin waves arise from the exchange couplings between the spins of the precessing magnetic dipoles, whereby any disturbance of one spin causing it to precess is coupled to adjacent spins and so on through the crystal, thus propagating energy in a wavelike mode. The propagation constant for spin waves is dependent on the direction relative to the applied magnetic field (which aligns the spins), on the magnitude of the field, and on the demagnetising factors. In the simple case of spin waves

with wavelengths short compared with the sample dimensions and propagating in the direction of the local field (H) then:

$$\omega = \gamma H + \gamma D k^2$$

where ω is the angular frequency of the spin waves, γ is the gyro-magnetic ratio, D is the exchange constant (equal to 5×10^{-9} Oe cm² for yttrium-iron garnet) and k is the wave number.

A particularly strong interaction is to be expected if the spin waves and the acoustic waves have the same wave vector, or phase velocity, as well as the same frequency. This can be arranged in practice by adjusting the field or the sample size. Exchange and electromagnetic retardation effects in the spin system can therefore be ignored, since these are important only at k values much greater than the acoustic wave number (for Rayleigh waves $\lambda_R > 20 \mu\text{m}$). In the presence of acoustic vibrations, the magnetisation exhibits a resonance response, and conversely it is possible to utilise the magnetic system to generate phonons of the spin wave frequency. If the coupled modes are both of plane wave form, which results when the sample size grossly exceeds the spin wavelength, the field symmetry ensures that spin waves propagating along or perpendicular to the magnetic field couple only to elastic shear waves. Such propagation directions are preferred in the present device since arbitrary propagation angles allow simultaneous excitation of compressional elastic waves, thus producing a loss of pumping power. In the case of YIG, strong magnetoelastic coupling should result from surface wave propagation parallel to the magnetic field when this is applied in a [100] crystallographic direction. This case is envisaged in the drawing.

Due to the internal demagnetising field, in none ellipsoidal samples the internal field is non-uniform and only a narrow region may be at exact magnetic resonance with the elastic wave frequency $\omega = \gamma H_{\text{int}}$. However if the magnetoelastic coupling is strong and the sample is suitably long, a sufficiently coherent modal interaction over hundreds of wavelengths at 300 MHz can readily be achieved. This enables travelling wave parametric amplification of phonons to occur in the magnetoelastic wave by absorption of pumping power, and the gap coupler then transfers a reinforced acoustic surface wave back onto the lithium niobate or other piezoelectric substrate.

The effect achieved is thus amplification of the acoustic wave transmitted over the surface wave delay line in the appropriate propagation direction. A concomitant advantage is that unwanted reflected acoustic waves will attenuate.

WHAT WE CLAIM IS:—

1. A surface acoustic wave amplifier

comprising a body of piezoelectric material having on a flat surface thereof a pair of separate input and output electroacoustic transducers arranged so that a surface
5 acoustic wave launched from the input transducer will be received by the output transducer, a plate of monocrystalline magnetic material capable of propagating spin waves excited therein located parallel to and
10 spaced apart from the flat surface of the piezoelectric material between the transducers thereon, the magnetic material having on a flat face thereof means for coupling a pump frequency current to the mag-
15 netic material so that spin waves induced in the magnetic material by magnetoelastic coupling with surface waves in the piezoelectric material are amplified and propagated in the same direction as the surface
20 acoustic waves in the piezoelectric material, and means for applying to the magnetic material a polarising magnetic field aligned with the direction of propagation of the surface acoustic and spin waves.

25 2. An amplifier according to claim 1

wherein the piezoelectric material is lithium niobate.

3. An amplifier according to claim 1 or 2 wherein the monocrystalline magnetic material is gallium-doped yttrium-iron-
30 garnet (YIG).

4. An amplifier according to claim 1, 2 or 3 wherein the means for coupling a pump frequency current to the magnetic material comprises a plurality of thin metallic film
35 spiral inductors disposed in a row on the surface of the magnetic material in the direction of the polarising magnetic field, the inductors being connected electrically in parallel.

5. An amplifier according to any preceding claim wherein the means for applying a polarising magnetic field is a permanent magnet.
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6. A surface acoustic wave amplifier substantially as described with reference to the accompanying drawing.
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COMPLETE SPECIFICATION

1 SHEET

This drawing is a reproduction of
the Original on a reduced scale.

